DEVELOPMENT OF MONOPOLE SENSORS FOR RICE QUALITY CHARACTERIZATION IN MALAYSIA

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Dedicated to my beloved family,

especially my mother; Saonah Binti Redzuan, my late father; Salleh Bin Talib,

my siblings,and also to a special someone who have encouraged, guided and

inspired me throughout my journey of education.

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ABSTRACT

This thesis presents an innovation within the established research of monopole sensors for the determination of the characteristics of rice in Malaysia. The characteristics are usually determined based on numerical method, simulation and experimental measurement. Measurements used to describe the grades and classify types of rice available in the market are based on moisture content and composition of broken rice. To characterize the quality of rice, various types of sensors have been used. In this research, two types of sensors : monopole sensor and coupled monopole sensor on a ground plane were developed. These sensors operate within the frequency range of 1 GHz to 5 GHz for moisture content characteristics and 10 GHz to 14 GHz for broken rice composition characteristics. These two types of sensors were used to measure ten different types of rice prepared using a standard oven method with moisture contents of between 14% to 18%. Besides that, five samples of different compositions of broken rice ranging between 0 to100% were also measured. To compare the two types of monopole sensors, the reflection coefficient of each sensor was measured at the feed point of the sensors by a Vector Network Analyzer (VNA) and analyzed using MATLAB software. The coupled monopole sensor showed a higher sensitivity of moisture content in the rice grain at 3 GHz with a value of 0.16 ($\%^{-1}$) in comparison to the monopole moisture content with a lower value of 0.07 ($\%^{-1}$). In addition, the coupled monopole sensor for the composition of broken rice in the samples at 12 GHz with a value of 0.00066 ($\%^{-1}$) was also more sensitive than the monopole sensor which had a lower value of 0.00037 ($\%^{-1}$). The findings have proven that the coupled monopole sensor is more sensitive than the monopole sensor.

ABSTRAK

Tesis ini mengemukakan inovasi dalam penyelidikan yang diwujudkan ke atas sensor-sensor monopole untuk menentukan ciri-ciri beras di Malaysia. Kebiasaannya, ciri-ciri ini ditentukan berdasarkan kaedah berangka, simulasi dan pengukuran eksperimen. Pengukuran yang digunakan untuk menggambarkan gred dan mengelaskan jenis beras yang terdapat dipasaran adalah berdasarkan kandungan kelembapan dan komposisi beras hancur. Untuk mencirikan kualiti beras, pelbagai jenis sensor telah digunakan. Di dalam kajian ini, dua jenis sensor : sensor monopole dan sensor monopole berkembar pada satah bumi telah dihasilkan. Sensor-sensor ini beroperasi dalam julat frekuensi 1 GHz hingga 5 GHz untuk ciri-ciri kandungan kelembapan dan 10 GHz hingga 14 GHz untuk ciri-ciri komposisi beras hancur. Kedua-dua jenis sensor ini digunakan untuk mengukur sepuluh jenis beras yang berlainan yang disediakan menggunakan kaedah ketuhar piawai dengan kandungan kelembapan antara 14% hingga 18%. Selain itu, lima sampel yang mempunyai komposisi beras hancur yang berbeza antara 0 hingga 100% juga diukur. Bagi membandingkan dua jenis sensor monopole, pekali pantulan setiap sensor diukur pada titik suapan sensor oleh Vektor Rangkaian Penganalisa (VNA) dan dianalisis menggunakan perisian MATLAB. Sensor monopole berkembar menunjukkan kepekaan yang lebih tinggi pada kandungan kelembapan di dalam beras pada 3 GHz dengan nilai 0.16($\%^{-1}$) berbanding dengan kandungan kelembapan sensor monopole yang lebih rendah iaitu 0.07($\%^{-1}$). Di samping itu, sensor monopole berkembar untuk komposisi beras hancur di dalam sampel juga lebih peka pada 12 GHz dengan nilai 0.00066($\%^{-1}$) berbanding sensor monopole yang mempunyai nilai yang lebih rendah iaitu 0.00037($\%^{-1}$). Penemuan ini telah membuktikan bahawa sensor monopole berkembar adalah lebih peka daripada sensor monopole.

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LIST OF ABBREVIATIONS

VNA	-	Vector Netwok Analyzer
MATLAB	-	Matrix Laboratory
MARDI	-	Malaysian Agricultural Research and Development Institute
CVS	-	Computer Vision System
RiPE	-	Real Time Rapid Rice Population Estimation
FEM	-	Finite Element Method
MUT	-	Material Under Test
MoM	-	Moment of Method
FDTD	-	Finite Difference Time Domain
NDT	-	NonDectructive Testing
TEM	-	Transverse Electromagnetic Mode
EMF	-	Electromagnetic Field
CST	-	Computer Simulation Technology
COMSOL	-	Communication Solution
PTFE	-	Polytetrafluorethylene (teflon)
SMA	-	Sub-Miniature A
PEC	-	Perfect Electric Conducting

LIST OF SYMBOLS

h	-	length of monopole
a	-	radius of inner monopole
b	-	radius of outer monopole
d	-	spacing between parallel monopole
$m.c.$	-	moisture content
t	-	thickness of the sample
ε	-	permittivity
ε_r	-	relative complex permittivity
$\varepsilon_r^{'}$	-	dielectric constant
$\varepsilon_r^{''}$	-	loss factor
ε_m	-	dielectric constant mixture equation
ε_a	-	dielectric constant of air
ε_c	-	relative permittivity of coaxial line (PTFE)
ε_0	-	permittivity of vacuum
μ_0	-	free space permeability
μ_r	-	relative permeability
μ	-	permeability
σ	-	conductivity

v_1	-	volume fraction of material
λ	-	wavelength
$I(z)$	-	current distribution
$\vec{E}$	-	electric field
$\vec{H}$	-	magnetic field
$\vec{B}$	-	magnetic flux density
$\vec{D}$	-	electric displacement
$\vec{J}$	-	current density
ρ_q	-	charge density
ω	-	angular frequency
$H_\emptyset$	-	azimuthal componentof magnetic field for coaxial line
E_ρ	-	electric field at radius ρ
E_z	-	tangential component of the electrical field
A_z	-	vector potential at z-direction
z	-	distance from the centre point of aperture
ρ	-	radius coordinate of point at aperture
$\emptyset$	-	angle coordinate of point at aperture
η	-	intrinsic impedance of medium
j	-	square root of -1
k_0	-	free space wave number
k_1	-	coaxial line propagation constant
k_2	-	propagation constant in the external medium

Z_{in}	-	input impedance
V_{in}	-	input voltage
$\tilde{Z}_{in}$	-	normalized input impedance
$I(0)$	-	driving point current
Z_{11}	-	self impedance
Z_{12}	-	mutual impedance
$\tilde{Z}_{11}$	-	normalized self impedance
$\tilde{Z}_{12}$	-	normalized mutual impedance
$\tilde{Z}_{in\_port1}$	-	normalized input impedance of monopole 1
$\tilde{Z}_{Aperture}$	-	normalized impedance at aperture
$\lvert\Gamma\rvert$	-	magnitude of reflection cofficient
$\Gamma_{AA'}$	-	reflection coefficient at plane *AA'*
$\Gamma_{Aperture}$	-	reflection coefficient at aperture
Γ_{meas}	-	measured reflection coefficient
ϕ	-	phase of reflection coefficient
S_{11}, S_{12}	-	S-parameter
$m_{Before\ Dry}$	-	weighs of rice before drying
$m_{After\ Dry}$	-	weighs of rice after drying
R_{in}/Z_0-	-	normalized resistance
X_{in}/Z_0-	-	normalized reactance
C_f -	-	capacitance element circuit
$\tilde{Y}_m$	-	normalized admittance for monopole

$\tilde{Z}_{corrected\ \_m}$	-	normalized corrected impedance for monopole
$\tilde{Y}_c$	-	normalized admittance for coupled monopole
$\tilde{Z}_{corrected\ \_c}$	-	normalized corrected impedance coupled monopole
a'_0, a'_1, a'_2	-	coefficients of dielectric constant equation
a''_0, a''_1, a''_2	-	coefficients of loss factor equation
f	-	frequency
c_0, c_1, c_2	-	coefficients of magnitude reflection coefficient with moisture content for monopole
d_0, d_1, d_2	-	coefficients of magnitude reflection coefficient with moisture content for coupled monopole
e_0, e_1	-	coefficients of magnitude reflection coefficient with broken rice for monopole
f_0, f_1	-	coefficients of magnitude reflection coefficient with broken rice for coupled monopole

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

In this chapter, the background of the project is explained from overview of the rice and standard quality testing technique of rice in Malaysia, which is conducted by Malaysia Agricultural Research and Development Institute (MARDI). The problem statements of characterization of rice in Malaysia are discussed. After that, the objectives of the research based on the monopole sensors have been found. The framework of each chapter also has been summarized.

1.2 Background of the Project

Rice is the one of the most important crops that provides the carbohydrates that necessitated by human body. Generally, rice is the staple food for citizen in the world but more popular in Asia. In Malaysia, the most popular area to plant paddy is Kedah because of the strategic geographic area and have a good irrigation system, thus, Kedah also known as *"The Rice Bowl"*. Today, it can be seen that Malaysia request of rice is increasing every year from 1.8 million tonnes in 1995 to about 2.3 million tonnes in 2010 due to the increased population. So, this situation may cause the depending on imports of rice from neighbour countries, such as Thailand, Vietnam and India.

Generally, the importance of rice will be divided into a few categories that are based on nutritional, economical and cultural aspect. Based on the nutritional aspect, rice is the excellent source of carbohydrate that will provides a good energy source for human body. In terms of economical aspect, rice becomes an international market and main policies for exporters and importers. This is because rice is a plant which is a source of income for those who are working on it. However, not all rice is cultivated by a country utilized by consumers in the country. In connection with it, this will force the import and export of which to help developed the national economy. Besides providing as a source of food, rice is also an important cultural role in many countries. It is used for many different reasons such as fuel, leaves for roofing and artwork. For example, in Malaysia there are many history that is related to rice such as Malinja, Mahsuri, Padi Ria and Bahagia.

The many diverse uses of rice both domestically and for export, require the quality to be evaluated according to its suitability for specific end uses. The quality characteristics of paddy or rice is defined in many ways such as moisture content of paddy, purity degree, varietal purity, cracked grains, immature grains and discoloured or fermented grains. These characteristics are determined by the environmental weather conditions during production, crop production practices, soil conditions, harvesting, and post harvest practices. In this study, only two physical properties are focused which are moisture content and broken rice.

It has also been reported that both the dielectric constant and loss factor of cereal grain and oilseed measured at microwave frequencies increase linearly with bulk density and moisture content at fixed temperature (Jafari *et al.* 2010)

1.3 Overview of Rice

There are literally more than 40 000 different types of rice in this world but commonly, rice is categorized by its shape and sizes or length either long grain, medium grain or short grain. In fact, rice is a monocarp annual plant that usually grows between 1 and 1.8 meters tall with long slender leaves 50–100 cm long and 2–2.5 cm broad. For the rice cultivation, it can only be grown at suitable soil and have a good irrigation water system.

Rice consists of two species which are *oryza sativa* known as Asian rice and *oryza glaberrima* known as African rice. *Oryza glaberrima* is less common and less known as compared to *oryza sativa*. *Oryza sativa* is divided into *indica*, *javonica and japonica* subspecies. In Malaysia, there are two forms of rice that are most popular used by citizens: white grain and reddish brown grains. The main difference of these form of rice lie in the processing and nutritional content. Chart of species and types of rice is shown in Figure 1.1.

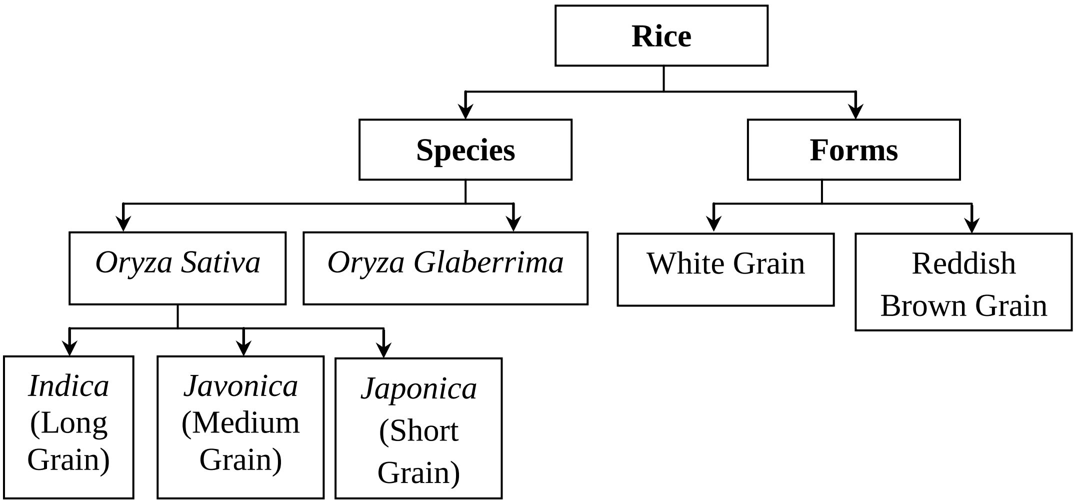


Figure 1.1: Species and forms of rice

For *oryza sativa Indica* it is also known as long grain rice. It has long and slender kernel which is at least 3 to 5 times longer than its width and it is easy to be recognize based on narrowest or skinniest of its shapes. In normally, typical length of long grain rice is 6 to 9 millimetres long. Besides that, this type of rice is commonly grown in warm climate region: Thailand, India, Pakistan, Brazil and Southern USA. Furthermore, long grain rice is much fluffier and less sticky compared to short grain rice.

In addition, medium grain rice has a size and length in between the other two grains which belongs to Javonica group called *oryza sativa Javonica*. It is shorter; plump which is slightly wider than long grain rice but not round. The length of this rice is 2 to 3 times longer than its width which is about 6 millimetres. But, it is only grown in Indonesia.

Besides that, the other type of grain rice is short grain rice. Long grain rice is narrowest and skinniest, whereas short grain rice is short, fat and almost round kernel. It is belongs to Japonica group called *oryza sativa Japonica*. It has size of almost as long as its width about 4 millimetres long and 2.5 millimetres wide. Short grain rice needs a cold weather environment to grow such as at Japan, Korea, Northern China and California. In particular, it has high starch content, moist and viscous. Table 1.1 shows the summary of properties of *oryza sativa* species.

Table 1.1: Properties of *oryza sativa* species

Properties	***Oryza sativa***		
	Indica	***Javonica***	***Japonica***
Common Name	Long grain rice	Medium grain rice	Short grain rice
Shapes	Long and slender kernel	Shorter, plump and wider kernel	Short, fat and almost round kernel
Size	3 to 5 times longer than its width (6-9 mm long)	2 to 3 times longer than its width (6 mm)	Length almost as long as its width (4 mm)
Grown Country	Thailand, Pakistan, Brazil and Southern USA	Indonesia	Japan, Korea, Northern China and California
Characteristics	Fluffier and less sticky		High starch content, moist and viscous

In the process of producing rice, brown rice went through an easy and simple step as compared to the white rice. After the paddy begins to mature, the irrigated rice field must be dry to operate the harvesting process. Once harvested, the rice is commonly named paddy rice. This is the name given for unmilled rice with its protective husk in place. Next step is milling using rice husker. During this process, the outermost layer of grain (husk or hull) is removed and leaves bran layers which is colored either in brown, reddish or black. To produce white rice, an added step is required. The individual grains are further stripped: the inner husk and germ and also removed to leave mostly the starchy endoplasm and the grains are polished to be white and smooth using glucose or talc. The structure of rice is shown in Figure 1.2

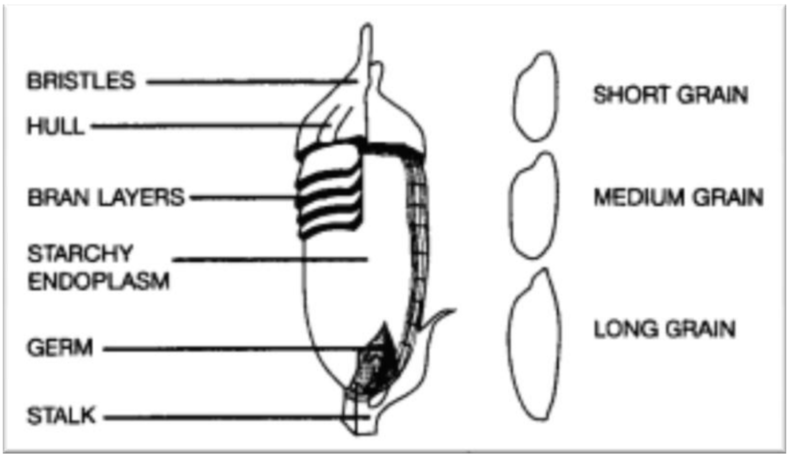


Figure 1.2: Rice structure

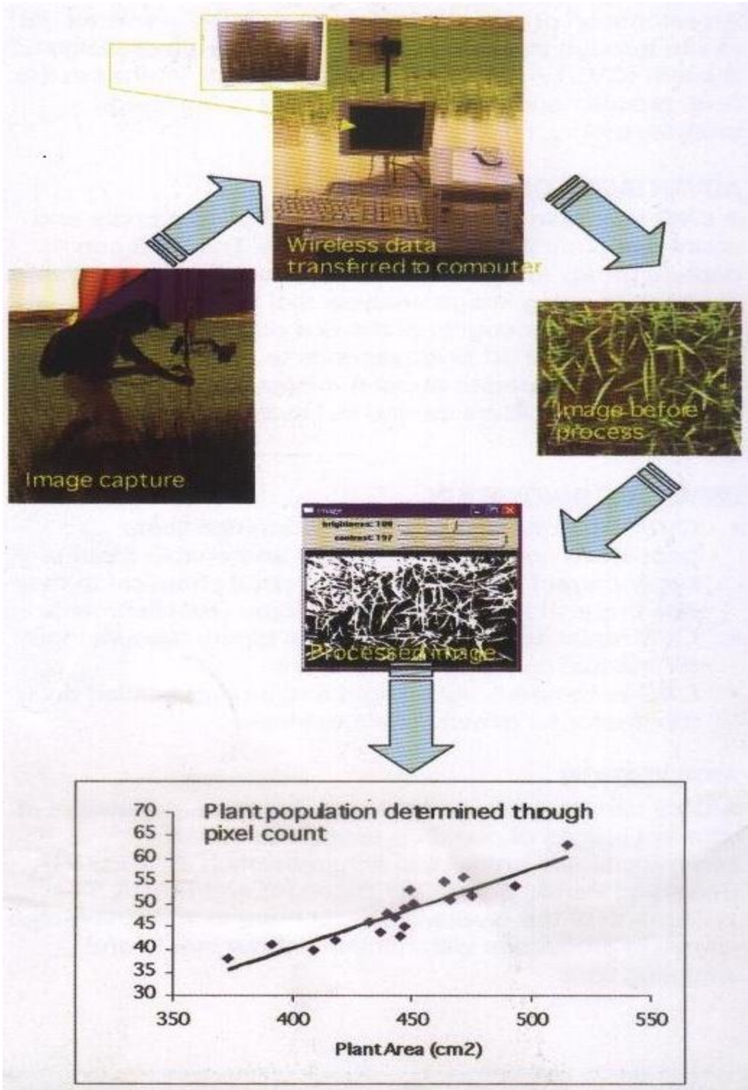
In terms of nutritional content, polished rice and parboiled rice falls into unenriched rice category which are different from enriched rice. The following Table 1.1 shows the basic nutritional value of white rice, parboiled rice and brown rice.

Table 1.2: Basic nutritional value of white rice, parboiled rice and brown rice (USDA, 2002)

Rice (1/4 cup raw)	**Calories (kcal)**	**Carbohydrates (g)**	**Fat (g)**	**Fiber (g)**	**Protein (g)**
White rice (unenriched)	169	36.98	0.31	0.60	3.30
Parboiled rice (unenriched)	172	37.80	0.26	0.79	3.14
Brown rice (enriched)	171	35.72	1.35	1.62	3.64

1.4 Quality Testing Techniques for Rice

Nowadays, there are many testing techniques used by Malaysian Agricultural Research and Development Institute (MARDI) to characterize the quality of rice. One of them is through image processing of a Computer Vision System (CVS). A CVS can capture paddy images in field, process and analyse the images using image analysis tool. This system uses Real Time Rapid Rice Population Estimation (RiPE) Software that is applied to monitor rice tillers population at different stages of rice crop. Figure 1.3 shows the flow chart of image processing using CVS.



. **Figure 1.3:** Process of image processing using CVS (MARDI, 2010)

Furthermore, MARDI also uses pest counter and collector to improve the quality of rice. It is because pest outbreaks can cause serious economic losses in terms of chemicals and labour used as well as the actual rice yield loss. This tool is easy to operate, time saving, fast, reliable and efficient. The prototype of pest counter and collector is shown in Figure 1.4.

Figure 1.4: Prototype of pest counter and collector (MARDI, 2010)

1.5 Problem Statements

Due to the world and domestic economic crisis, the prices of goods have increased rapidly and it affects the price of rice which is a staple food for most of Malaysian. Nowadays, there are many brands and grade of rice commercialize in the market because of the high demand from the consumer. Thus, this increases the need to characterize the quality of rice properly and hence to determine the price of rice appropriately. Others equipment in the market required high cost maintenance and not friendly user. For example, grain moisture meter are less accurate, need high human effort and time consuming. Monopole sensors are a technique that can be used for this purpose to measure the quality of rice accurately and quickly. Monopole sensors present various advantages such as

1.6 Objectives

The main objectives of this work are to develop and investigate the monopole sensor and coupled monopole sensor, as well as to simulate the characterization of rice. This study is to:

1) Construct a low cost and sensitive monopole sensors using theory of monopole and coupled monopole

2) Describe the relation between reflection coefficient with moisture content, *m.c.* of the rice and percentage of broken rice, which is tested by monopole sensor and coupled monopole sensor for frequency range 1 GHz to 5 GHz and 10 GHz to 14 GHz.

3) Monitor the relation between dielectric properties and moisture content, *m.c.* of the rice, which is tested by the small design of coaxial sensor for frequency range 0.2 GHz to 20 GHz.

1.7 Thesis Outline

The framework of the thesis is divided into six chapters. Chapter 1 contains the introduction of the research that consists of the background of the research, problem statement, objectives, scope of the research and framework of the thesis.

Chapter 2 presents the literature review of the research which includes the advantages and history of the sensor. The previous research that relates with the this work is discussed in detail

Chapter 3 reviews and summarize the theoretical and analytical analysis of monopole sensor and coupled monopole sensor. The chapter is emphasised on the derivation of the input impedance, $\tilde{Z}_{in}$ for both sensors. In addition, the calibration of the sensors is also reviewed in this chapter.

Chapter 4 states the design and development of the sensors. In this chapter, the research methodology and dimensions of the sensors are described in detail. The measurement setup of each measurement is also explained in this chapter.

Chapter 5 focuses on the result and analysis of the measurements. The performance between simulated, analytical and measured result of both sensors are compared in terms of the reflection coefficient and input impedance. Besides that, the performance and quality of ten types of rice is also discussed.

Finally, Chapter 6 contains conclusion and future works. In this chapter, the advantages and findings of the research are concludes with some recommendation for future works.

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